MICE Update

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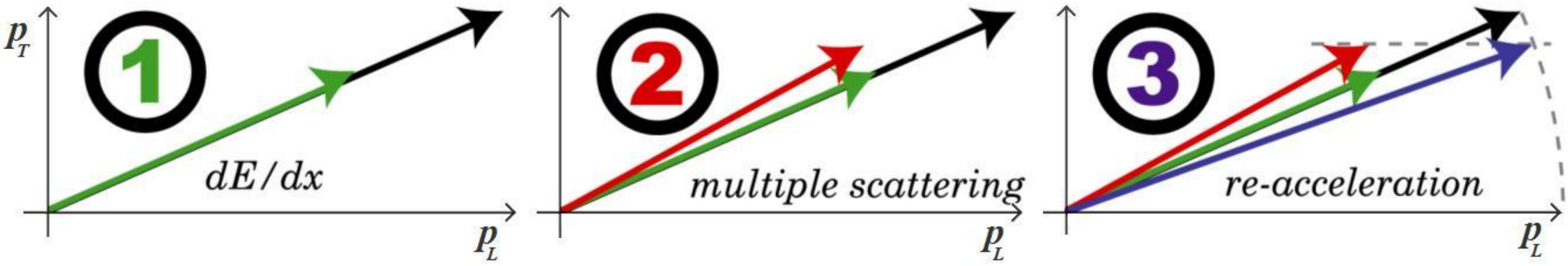
03/12/2014, SLAC, MAP meeting

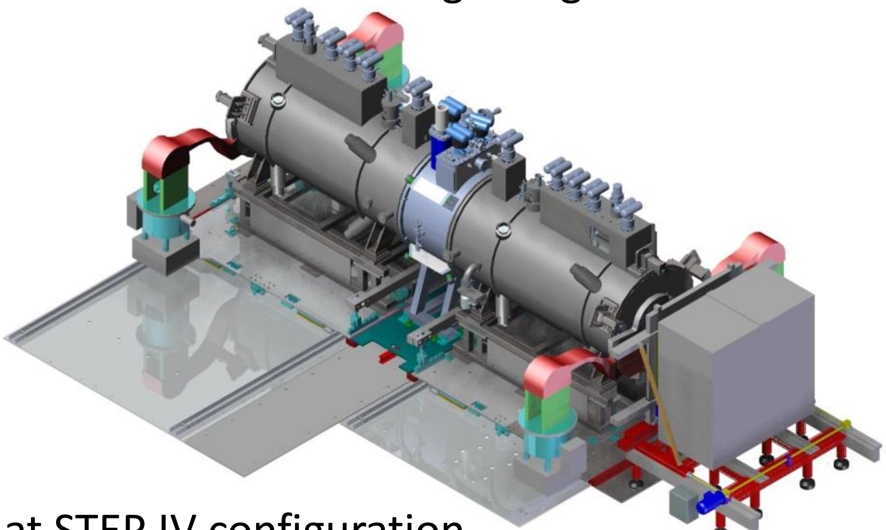
Outline

- Introduction
- Preparations for Step IV
- MICE Demonstration of Ionization Cooling (MDIC)
- Summary

Basics of ionization cooling

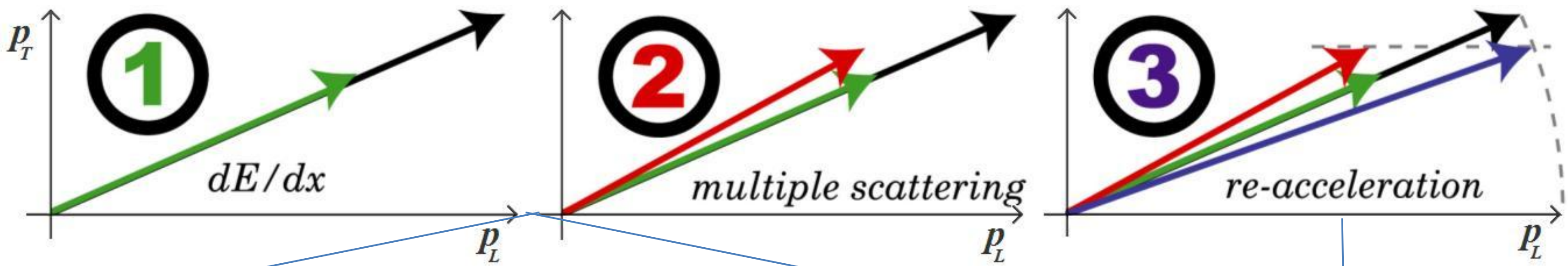


- Muons pass trough absorber (liquid hydrogen) and acelerating cavity (RF).
- As a net effect transverse momentum is reduced.
- Strong focusing (using solenoids), low Z material as absorber and high RF gradient are necessary.
- It has never been demonstrated yet, but...
- It will be done in world's first muon cooling device - MICE (Muon Ionization Cooling Experiment)



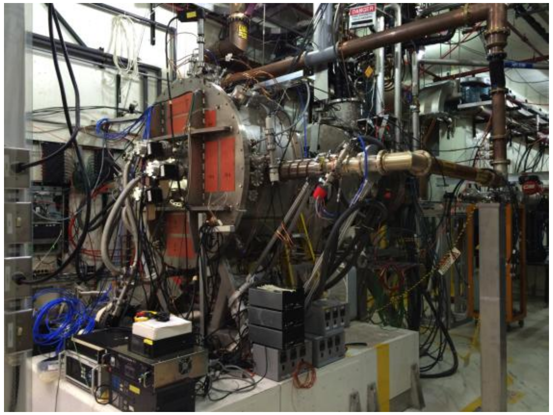
MICE at STEP IV configuration

Basics of ionization cooling (2)



LiH disk

LH2 system



Single Cavity Test Stand (SCTS) at MTA, FNAL

Ionization cooling equation

Depends on the input beam

Depends on magnetic lattice

$$\frac{d\varepsilon}{ds} = \frac{-\varepsilon_n}{\beta^2 E}\left\langle\frac{dE}{dX}\right\rangle + \frac{\beta_t (13.6\ \mathrm{MeV})^2}{2\beta^3 E m_\mu X_0}$$

$$\frac{p}{E} = \beta,\ E = \sqrt{p^2 + m_\mu^2}$$

Depends on material

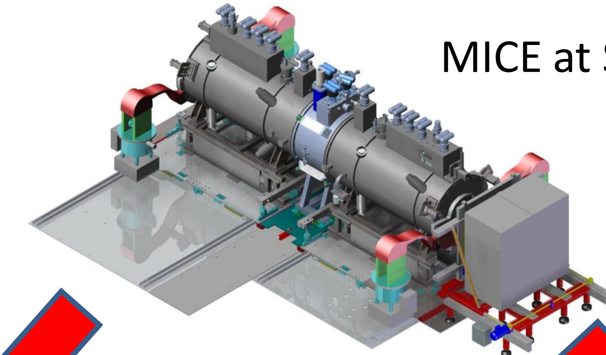
J. Pasternak

MICE goals

	Step IV	MDIC
Study of properties that determine cooling performance		
Cooling properties of LH_2 and LiH	**Yes**	**No**
Observation of $\epsilon_\perp^n$ reduction	**Yes**	Yes
Demonstration of sustainable ionization cooling		
Observation of $\epsilon_\perp^n$ reduction with re-acceleration		**Yes**
Observation of $\epsilon_\perp^n$ reduction with $\epsilon_\parallel$ "management"		**Yes**
Observation of $\epsilon_\perp^n$ reduction with $\epsilon_\parallel \oplus \mathcal{L}$ "management"		**Yes**†

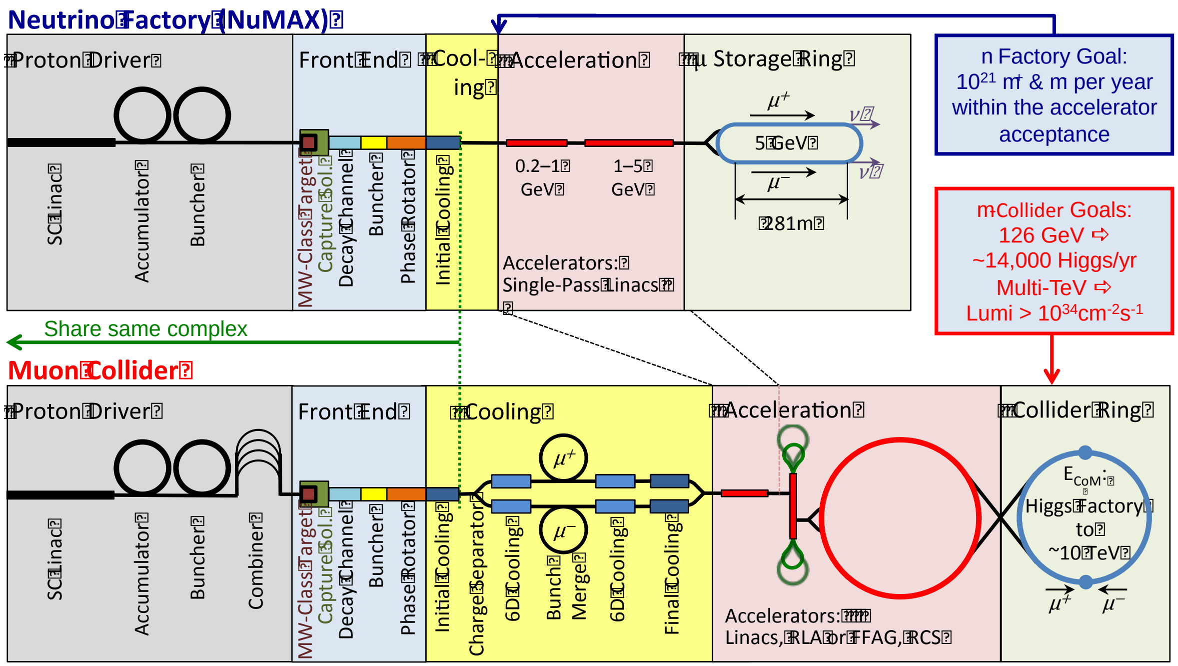
† Requires systematic study of "flip" optics.

MICE – path towards a future



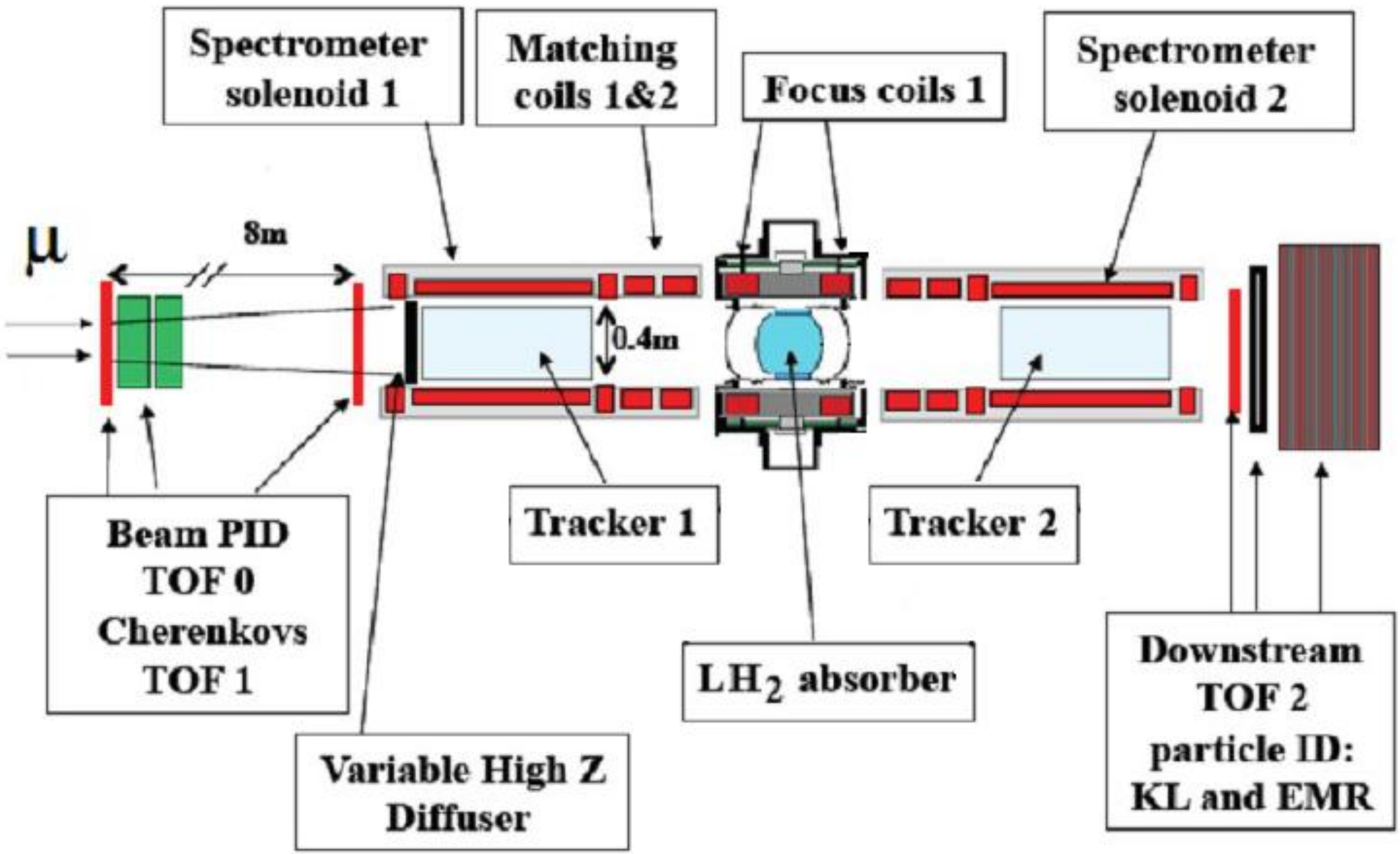
MICE at STEP IV configuration

MICE, once successfully completed will enable for exciting future applications of cold muns



High brightness beams for future precision experiments (rare muon decays, cLFV), applied science (muon spectroscopy), security applications, etc.

Step IV configuration – to be operational in 2015-2016



Step IV Schedule

Step IV		
1	Compressors ready for cooling channel tests	29th January 2015
2	Rack Room Complete	2nd February 2015
3	South side yoke material delivered	16th March 2015
4	South side return yoke installation complete	1st April 2015
5	North side yoke material delivered	28th April 2015
6	North side return yoke installation complete	14th May 2015
7	MICE Step IV installation complete	2nd June 2015
8	Combined magnet operational tests complete	11th August 2015
9	End of Step IV Data taking	1st June 2016

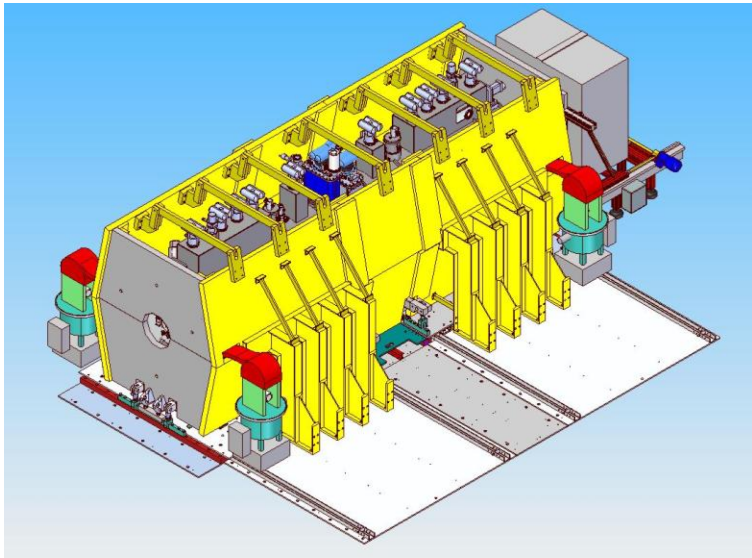
User Period	Start Date	End date	
1	17/3/2015	24/4/2015	Construction ongoing, possible beamline pre-commissioning
2	2/6/2015	24/7/2015	Magnet and beam commissioning
3	8/9/2015	16/10/2015	Physics
4	3/11/2015	18/12/2015	Physics
1	?	?	Physics

ISIS schedule

Progress towards Step IV

- Spectrometer solenoids:
  - ❑Upstream:
    - Tracker fitted; installed in MICE Hall; leak checked
  - ❑Downstream:
    - Tracker fitted; installed in MICE Hall; leak checked
- Focus coil:
  - ❑FC1:
    - Presently in MICE Hall; will be moved to R9 03Dec14
  - ❑FC2:
    - Electrically/magnetically superior to FC1;
    - Met acceptance criteria; field mapped; installed in Hall (03Dec14)
- Partial return yoke:
  - ❑Material … Procurement complete;
  - ❑Installation of "below-floor" structures underway;
  - ❑Above-floor framework complete (at Keller Tools Inc., NY);
  - ❑Plates delayed by 3 months:
    - Primarily due to procurement issues
- Software and analysis are progressing
- Commissioning and run plan have been created

- Excitement is growing!



Prioritisation of Step IV data taking:

- Pressures:
  - Completion and commissioning of Step IV;
  - Start of reconfiguration for cooling demo;
  - Staffing for safe operations 24/7 versus 16/5

1	Detailed scan (with $\sim$ 20k good muons per point) of the effect of empty, liquid-hydrogen and lithium-hydride absorbers as a function of betatron function (9 points) at the nominal momentum of 200 MeV/c.
2	1 & detailed scan (with $\sim$ 20k good muons per point) of the effect of empty, liquid-hydrogen and lithium-hydride absorbers as a function of momentum (9 points) at the (single) nominal betatron function (β) of 420 mm.
3	1, 2 & 100k good muons per point muons at the nominal $\beta = 420$ mm, $p = 200$ MeV/c, scanning over emittance (3 points) with empty, liquid-hydrogen and lithium-hydride absorbers.
4	1, 2, 3 & detailed scan (with $\sim$ 20k good muons per point) of the effect of liquid-hydrogen and lithium-hydride absorbers as a function of betatron function (9 points) and emittance (3 points) at the (single) nominal momentum of 200 MeV/c.
5	1, 2, 3 & sampling of 3×3 emittance, momentum matrix at three betatron functions with reduced sample size ($\sim$ 25k good muons per point).
6	1, 2, 3 & sampling of 3×3 emittance, momentum matrix at three betatron functions with reduced sample size ($\sim$ 50k good muons per point).
7	1, 2, 3 & sampling of 3×3 emittance, momentum matrix at three betatron functions with reduced sample size ($\sim$ 100k good muons per point).

Step IV Run Plan

User Period	Run Type	Absorber	Focus coil Mode	Run-time (days)	Total (days)
2	Commissioning			54	
3	Physics	Empty	Solenoid	18	
	LH2 Fill			2	
	Physics	LH2	Solenoid	18	38
4	Calib/Setup			7	
	Physics	Empty	Flip	18	
	LH2 Fill			2	
	Physics	LH2	Flip	18	45
1	Calib/setup			7	
	Physics	LiH	Flip	18	
	Physics	LiH	Solenoid	18	43
					126

Commissioning of Detectors

- TOFs, KL: no need for special commissioning.
- CKOVs: Equalise gains of PMTs, Cherenkov threshold scans
- EMR: hardware upgrade in progress, software integration into MAUS almost complete, documentation to be provided.
- Trackers: see next slides.

Tracker commissioning runs

- Readout commissioning – no beam, random and LED triggering to iron out VME based trigger logic – 2 days
- Calibration – no beam runs with LED varying bias, discriminator and TDCs (latter not Step 4 essential) – 4 days (bias) + 4 days (discriminators) + 4 days (timing) = 12 days
- Timing commissioning – starting with LED and moving to beam to ensure integration and veto period align with arrival of particles – 5 days
- Fiber efficiency – 1 hour LED, 2 hours beam
- Alignment checks – no field straight tracks (~25% transmission) to reconstruct actual alignment of tracker in reference frame – 1-5 days depending on previous commissioning

Tracker commissioning runs

- Three weeks, without beam
- Two weeks, with beam
- Total commissioning time alone is not enough – need time between commissioning and real running to analyze data, make adjustments, etc.
- Run 1: 15/4/15 – 24/4/15?
- Run 2: 2/6/15 – 23/6/15?
- Tracker should get unrestrained (by other detectors) time at the beginning of the commissioning period

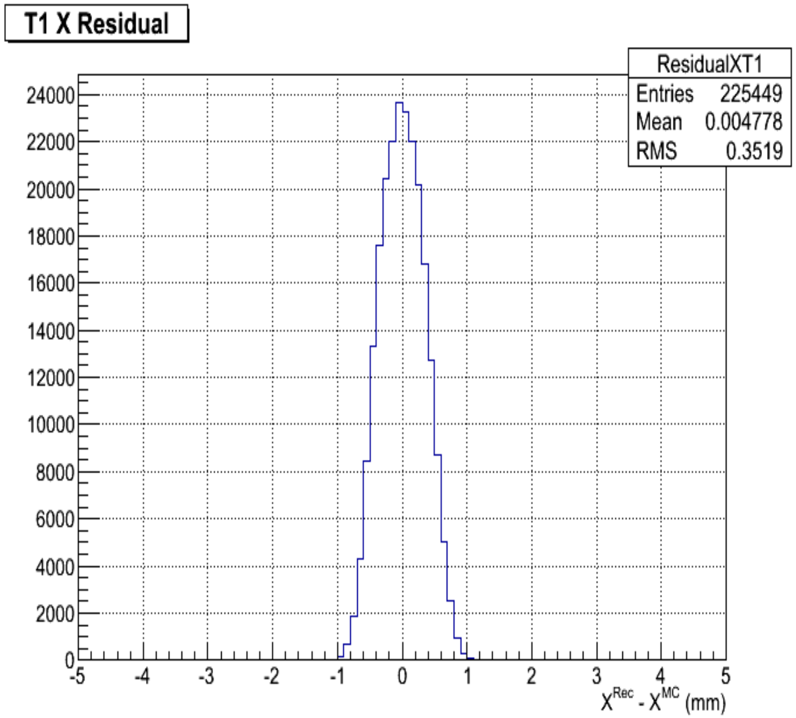
MICE magnets commissioning at STEP IV

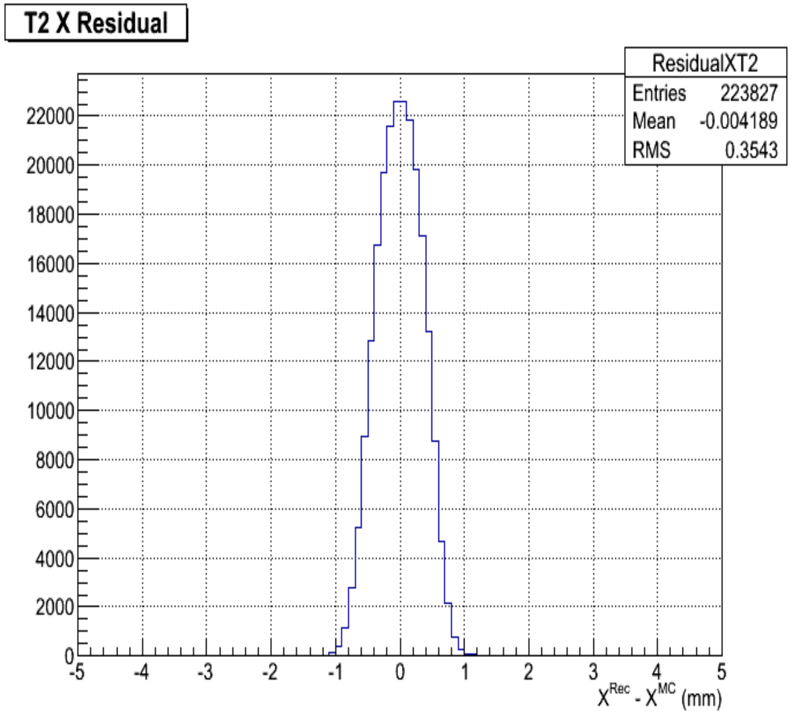
- Magnets will be installed, connected and a ramping test completed in advance.
- Sufficient supply of LHe needs to be secured
  - ❑ Discussions with BOC indicate Liquid Helium availability will not be an issue!
  - ❑ Each magnet will be equipped with its own dewar and the transmission line.
- It will be followed by individual magnet training
  - ❑ SS will be trained in parallel, but, only 1 magnet will be ramped at a time (1 quench per magnet per day and 2 quenches per day in 24/7 training operations).
  - ❑ We will start most likely in solenoid mode.
- Once all magnets reached their independent nominal settings, set nominal current in both SSs and start raising current in the FC.
  - ❑ Detecting which coil quenches first knowing the FC current will allow to assess how far we are from the nominal setting:
  - ❑ Depending on experimental findings the procedure may be followed by:
    - ❑ Training the FC with SS currents fixed at nominal (repeating the procedure).
    - ❑ Training the FC with SS currents fixed at derated value (to be defined).
    - ❑ Switching to combined training (Scenario 1 with ramping all magnets simultaneously at approximately 2.5 quench per week incl. 40% contingency)

Shift request for beam commissioning

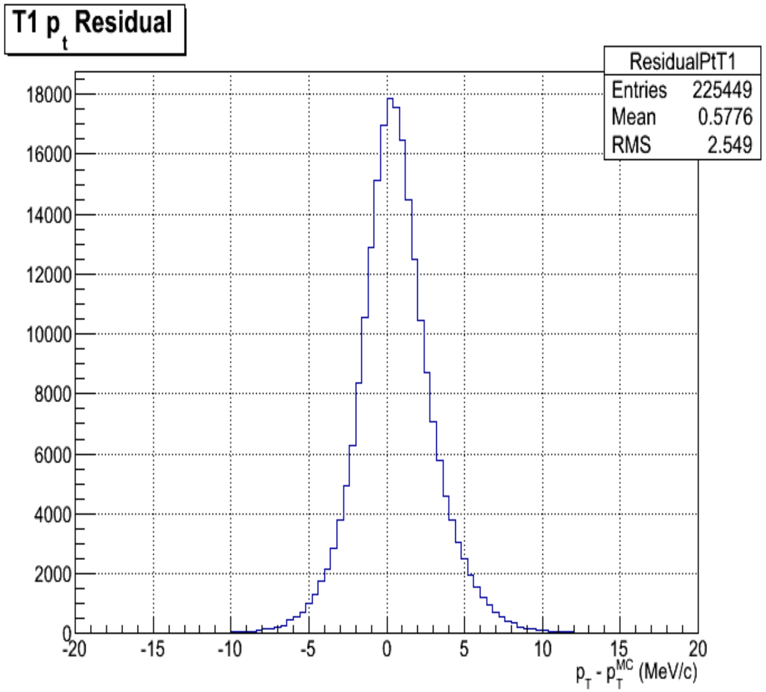
- Beam line pre-commissioning with beam (does not require Tracker)– 8 shifts
- Beam line commissioning including Diffuser and matching into Channel (requires Tracker - essential) – 15 shifts
- Beam Commissioning of MICE Channel - 21 shifts
  - At this stage we do not know, how much time is required, so this is only a guess.

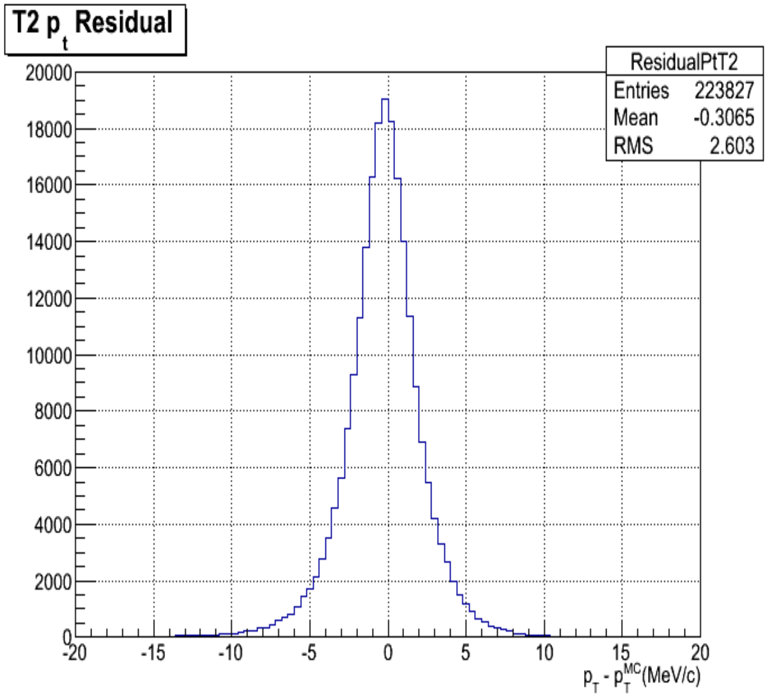
Tracker Position Residuals

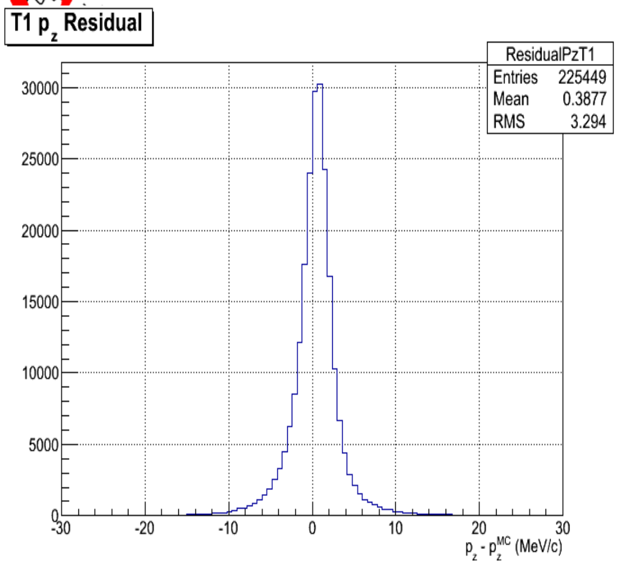


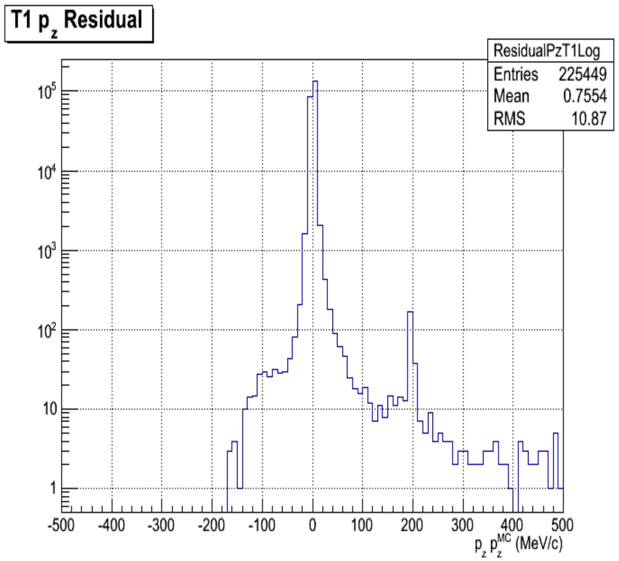


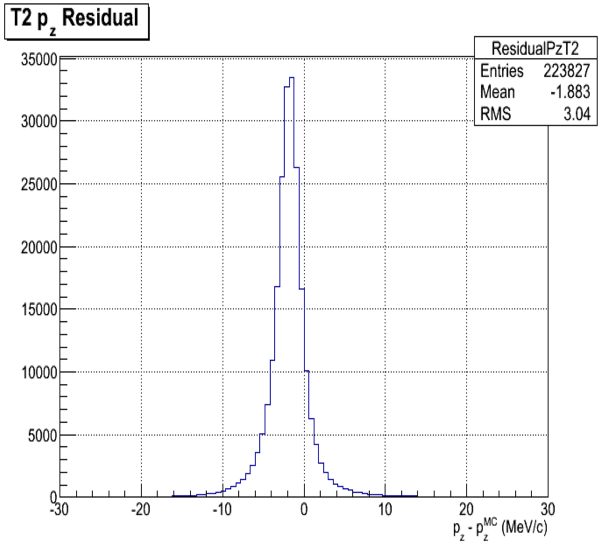
Tracker Momentum Residuals

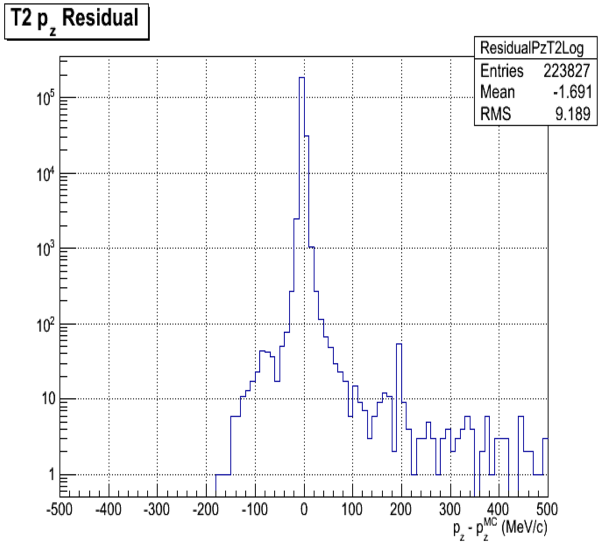






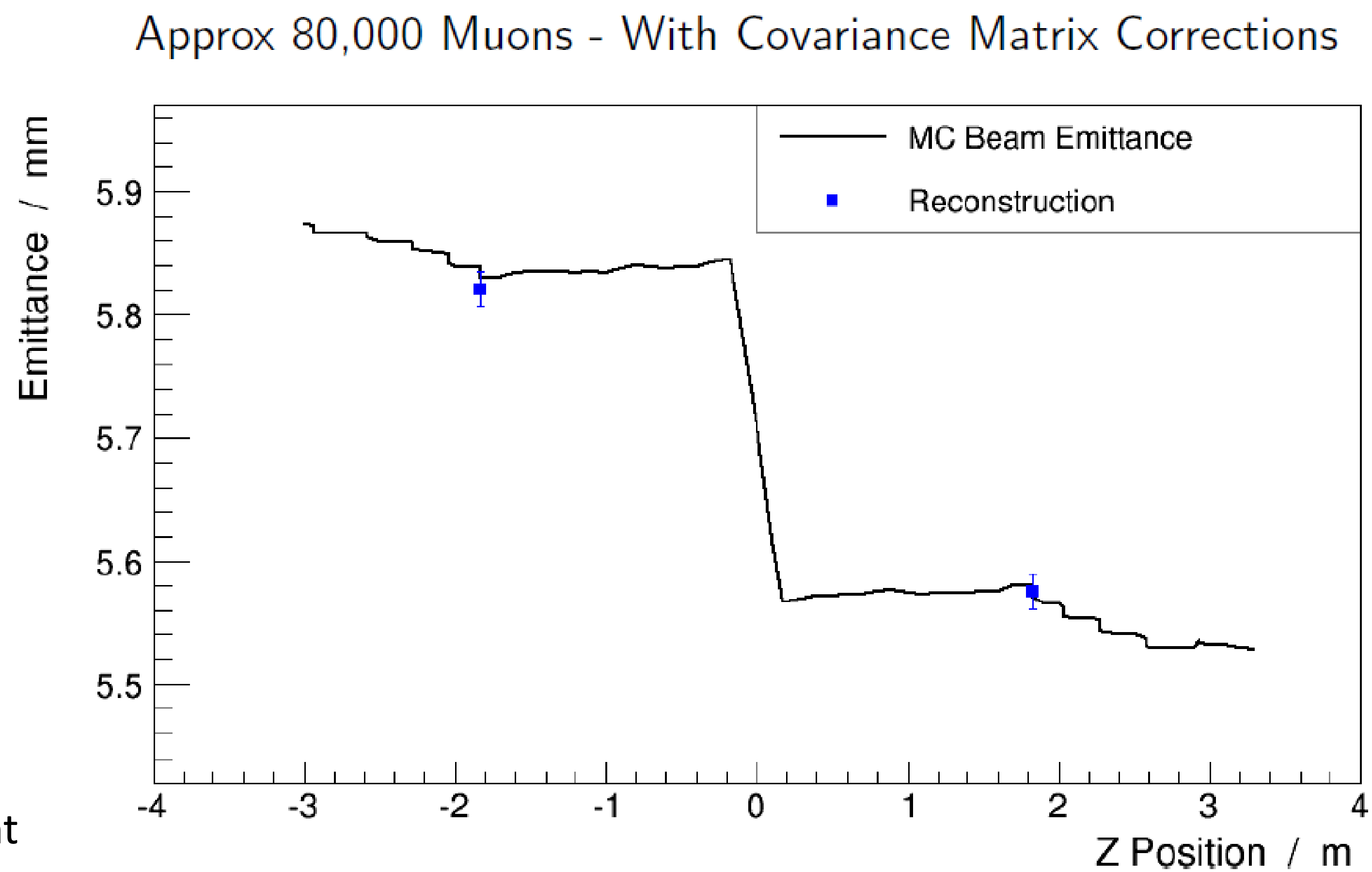






Tracker Longitudinal Momentum Residuals

Emittance Reconstruction at Reference Plane

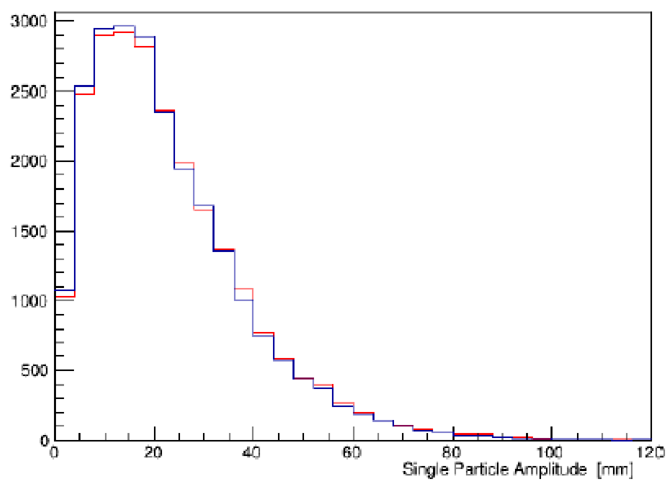


C. Hunt

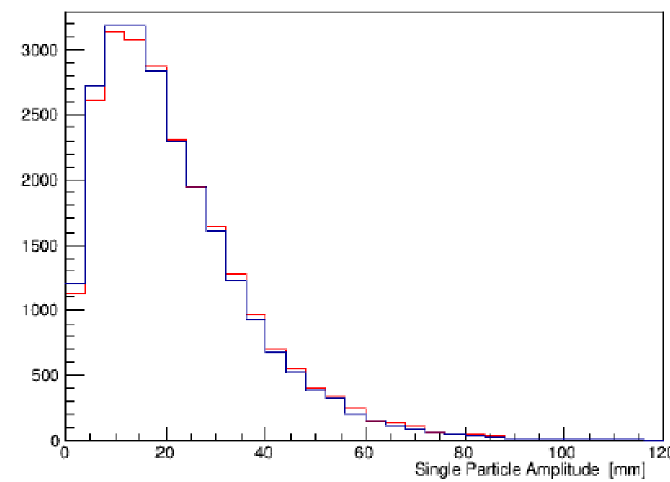
A 6πmm at 200MeV/c Positive Muon Beam using a Step IV Cooling Channel Geometry

Single Particle Amplitudes

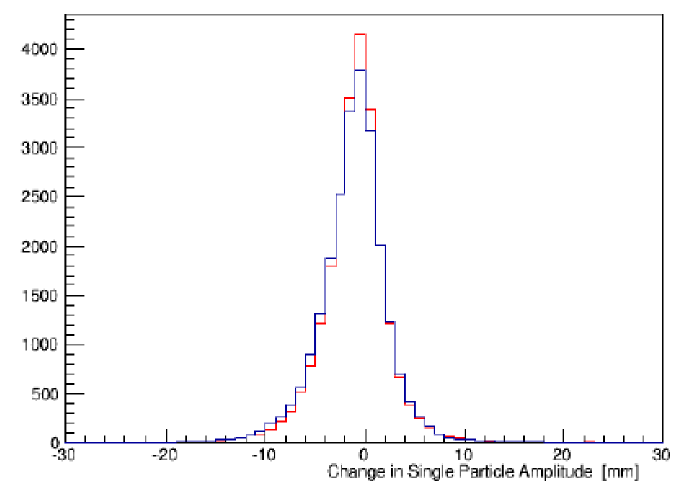
Upstream Reference



Downstream Reference



Amplitude Change

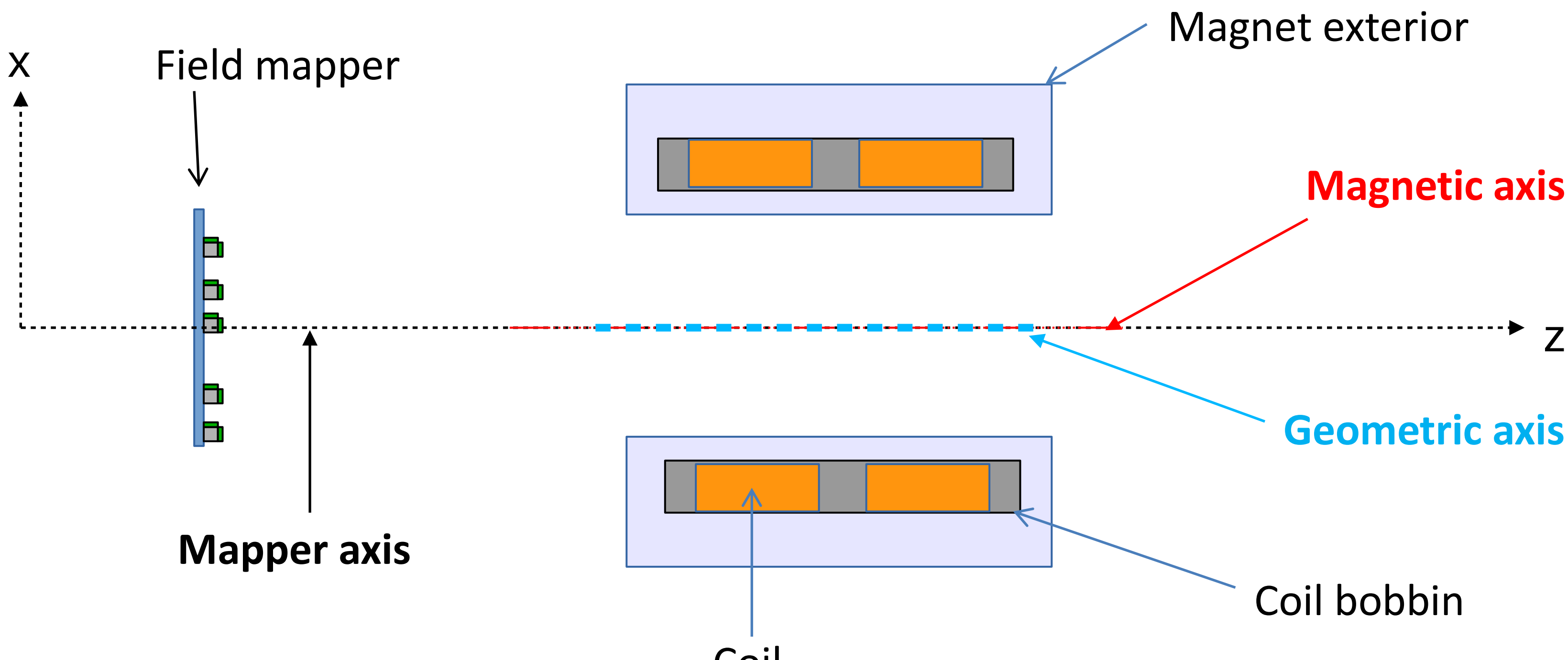


– Truth MC
– Reconstructed MC

Currently see a 1-2% emittance bias in the reconstruction, consistent for both trackers

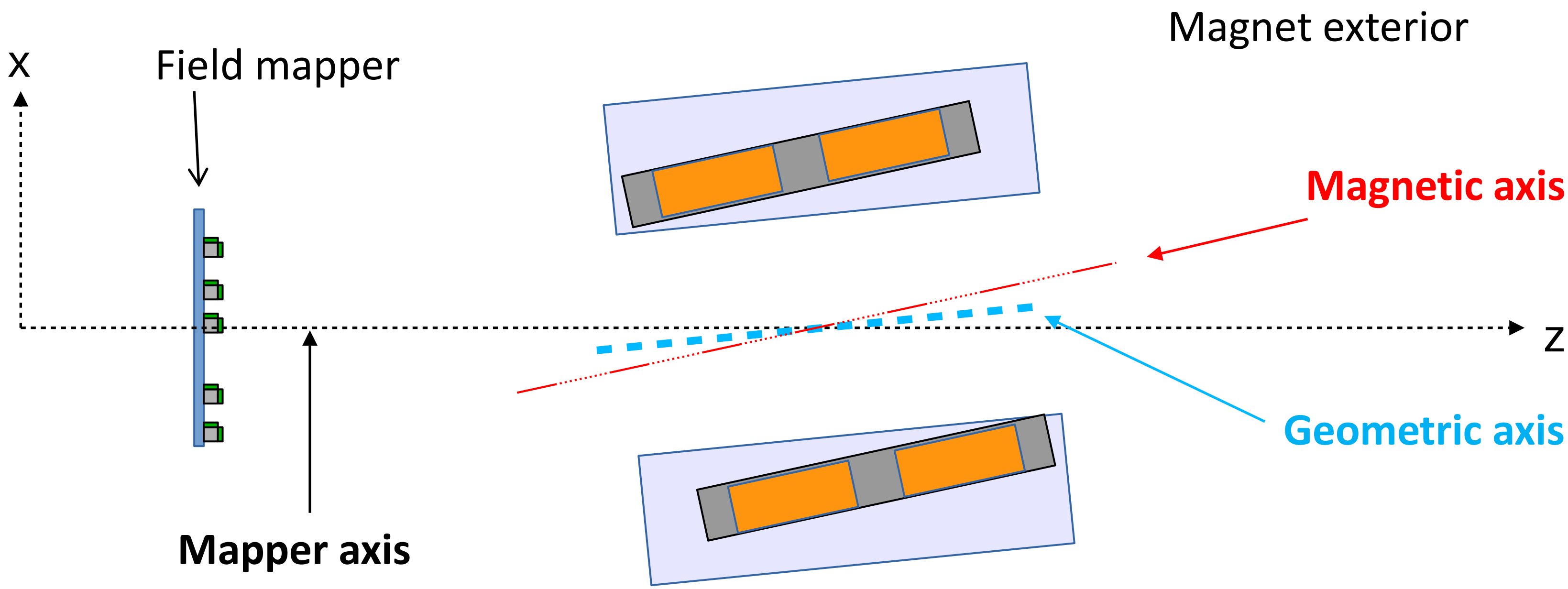
Field Mapping: Magnetic Axis Analysis

- In a perfect world…
  - The **magnetic axis** (defined by coil bobbins) is aligned to **geometric axis** (defined by survey)
  - The field **mapper axis** is aligned with the **magnetic** and **geometric** axes



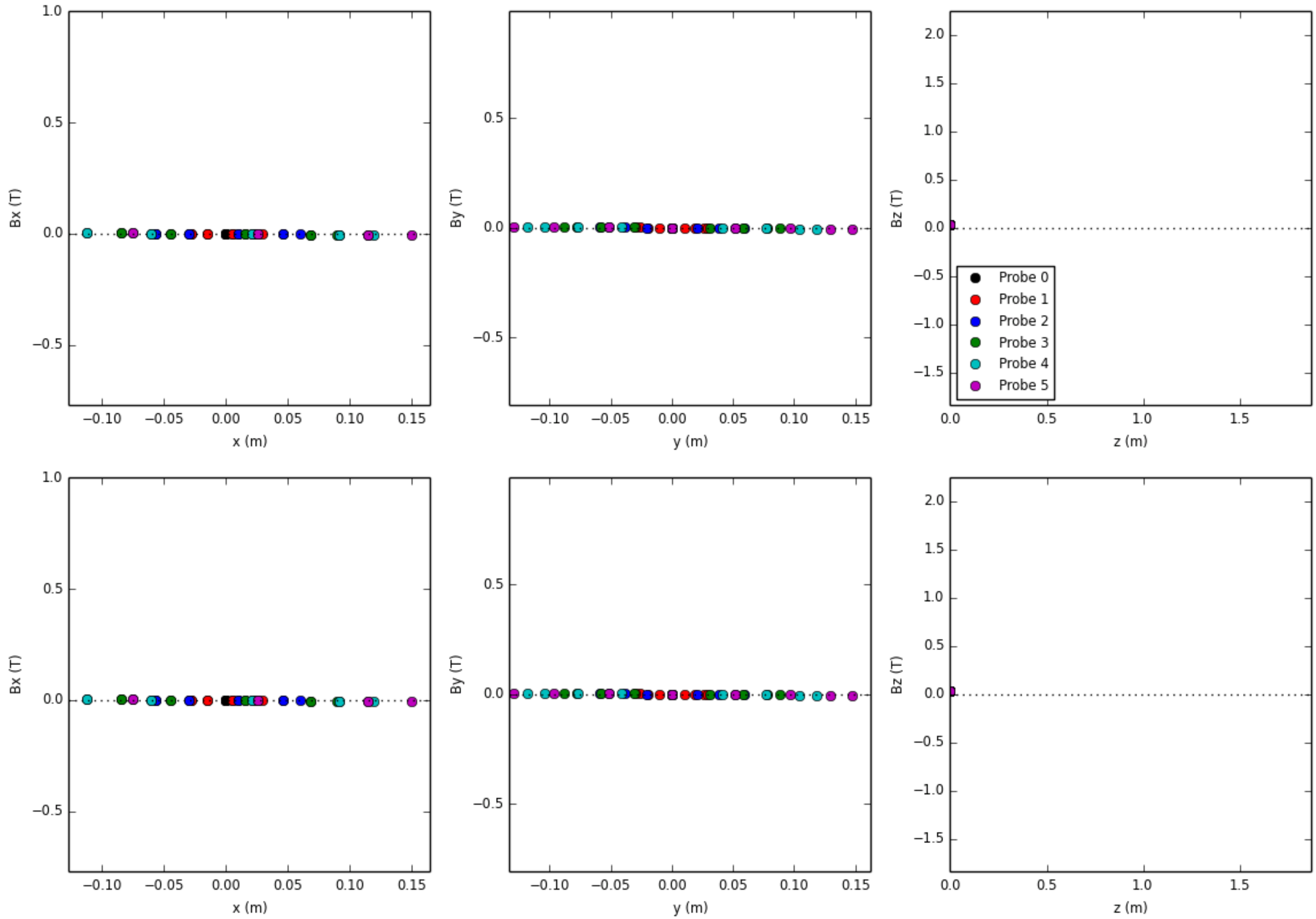
Field Mapping: Magnetic Axis Analysis

- In a realistic world…
  - The **magnetic axis** is not aligned to **geometric axis**
  - The field **mapper axis** is not aligned with the **magnetic** or **geometric** axes
  - We know the relationship between the **mapper** and **geometric** axes
  - We do not know the relationship between the **mapper** and **magnetic** axes



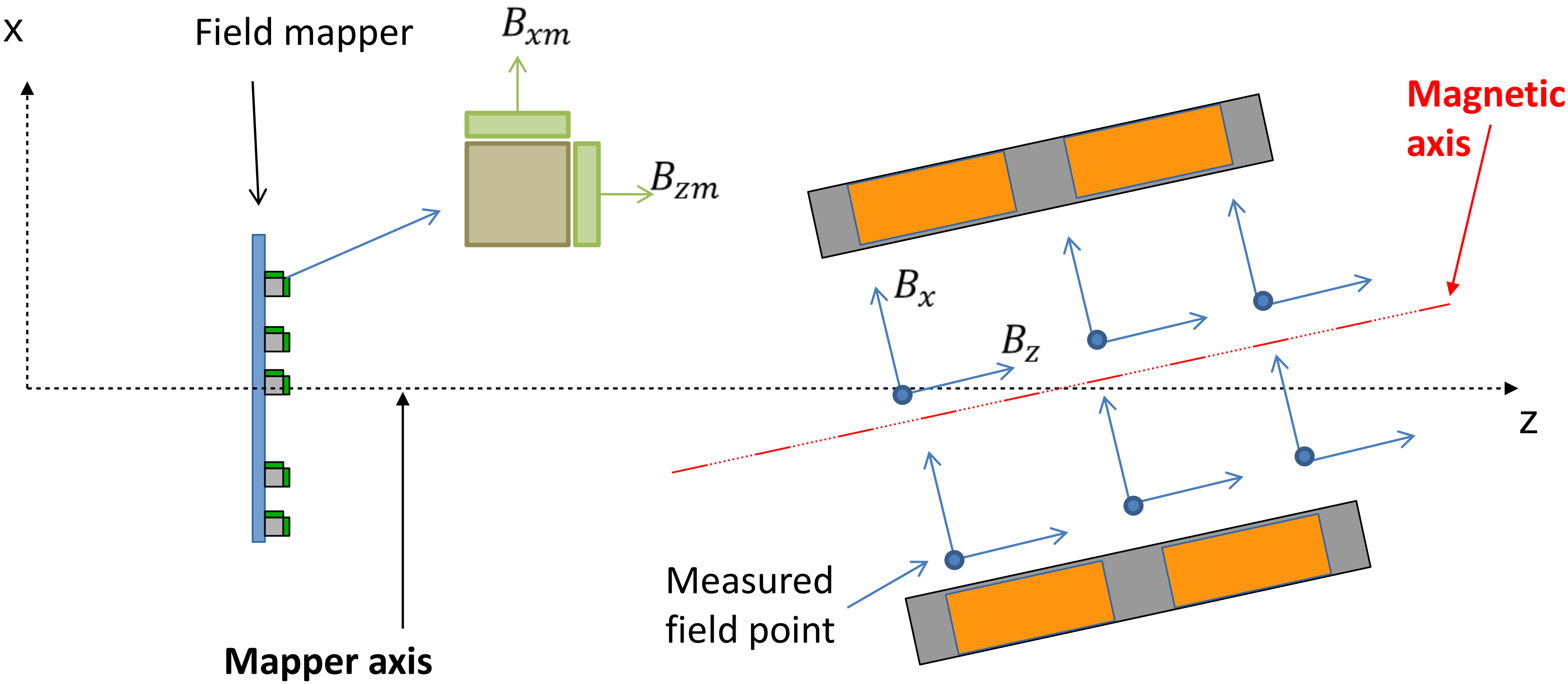
Field Mapping: The Naïve Analysis*

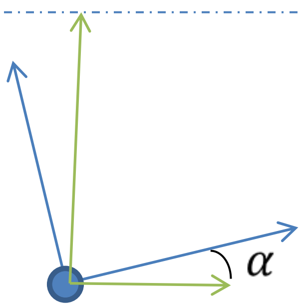
Calculated field from a Focus Coil operating at 150A in “flip mode”



*NB: This animated gif won’t display in a pdf

Field Mapping: Why So Naïve?





Mapper does not measure "pure" Bx and By, but includes a small amount of Bz

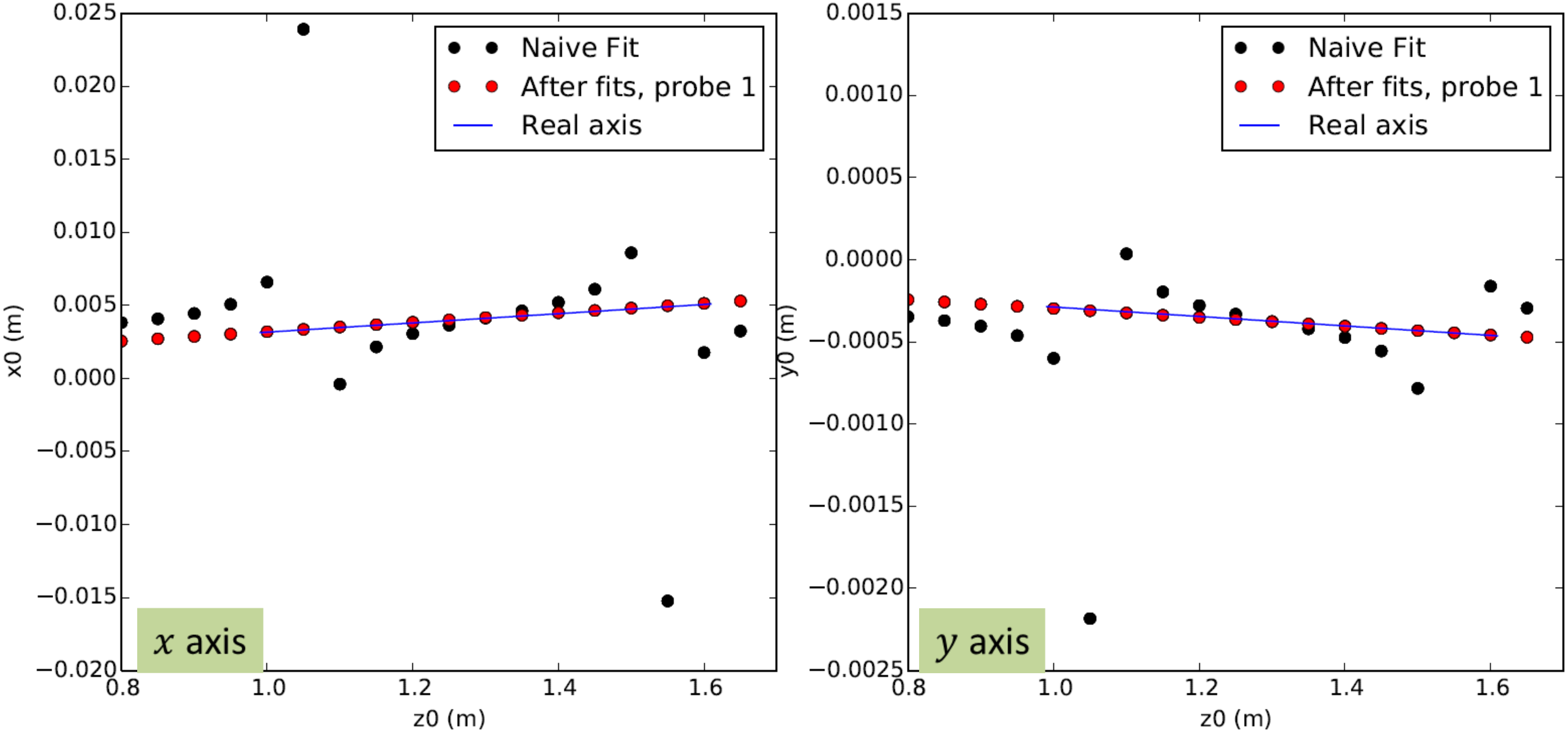
$$B_{xm} \approx B_x + \alpha B_z$$

$$B_{zm} \approx B_z + \alpha B_x \approx B_z$$

Field Mapping: Testing the theory

1. Define the **mapper axis** and the measured co-ordinates in **mapper space**.
2. Define a test magnet (FC-like, 150A, flip mode), whose **magnetic axis** is not aligned to the **mapper axis**.
3. Obtain the measured co-ordinates in **magnetic axis space**.
4. Calculate the **true field** measured at these co-ordinates, then translate them back into **mapper space**.
5. We now have a “field map” of a tilted magnet, and the challenge is to find the (known but unknown) tilts.

Field Mapping:Test # 1 (large tilt)

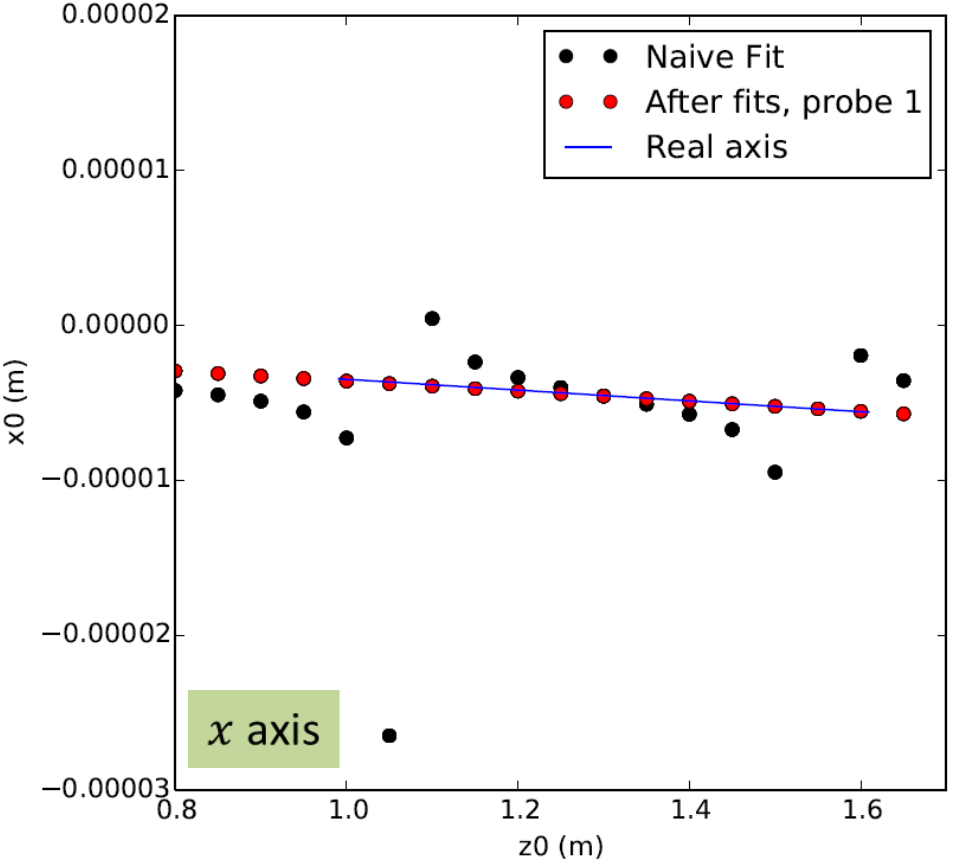


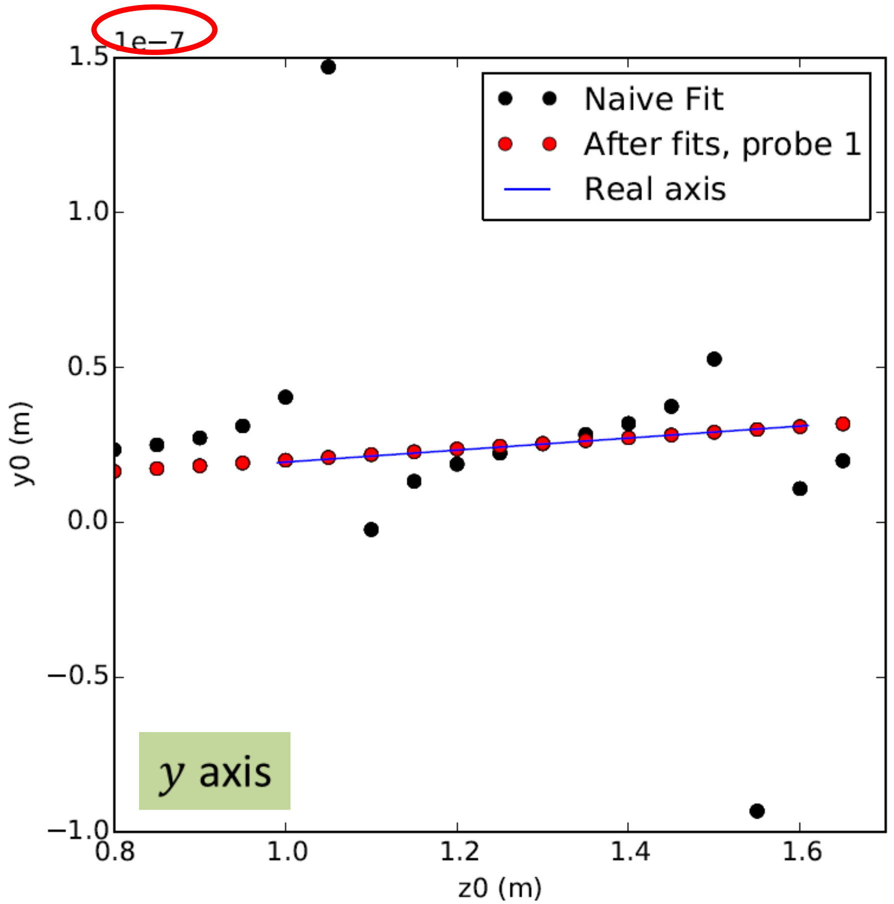
"Naïve fits": Assume a perfect world and ignore the fact that $B_{xm} \neq B_x$ etc

"After fits": Assumes a realistic world, finds α and axis

"Real axis": The line between the **known** upstream and downstream ends of the test magnet.

Field Mapping: Test # 2 (small tilt)





"Naïve fits": Assume a perfect world and ignore the fact that $B_{xm} \neq B_x$ etc

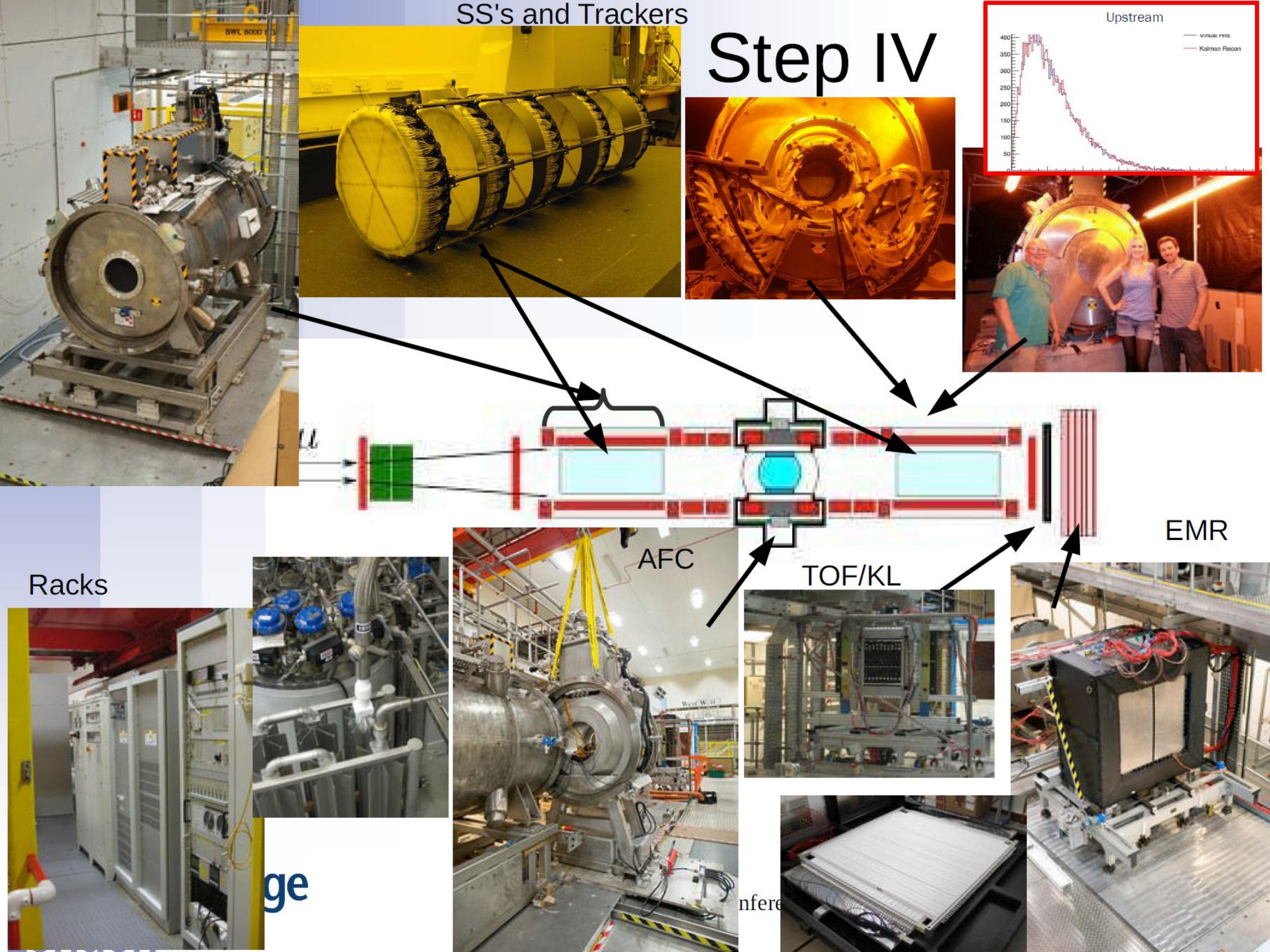
"After fits": Assumes a realistic world, finds α and axis

"Real axis": The line between the **known** upstream and downstream ends of the test magnet.

Progress on various other fronts

- MLCR Upgrade 75% complete (P. Smith)
- Huge progress in control and monitoring
- Global Tracking: focus to merge Trackers with TOFs
- Improvements in documentation
- MAUS is in good shape (MAUS team)
- CDB Geometry validated (Geometry team)
- Physics Block Challenge: test data generated, analysis in progress (R. Bayes)
- Electrical installations progressing well (S. Griffiths)
- LH2 system preparations in progress (S. Watson)
- Alignment team created and started working (S. Boyd)
- ....many more!

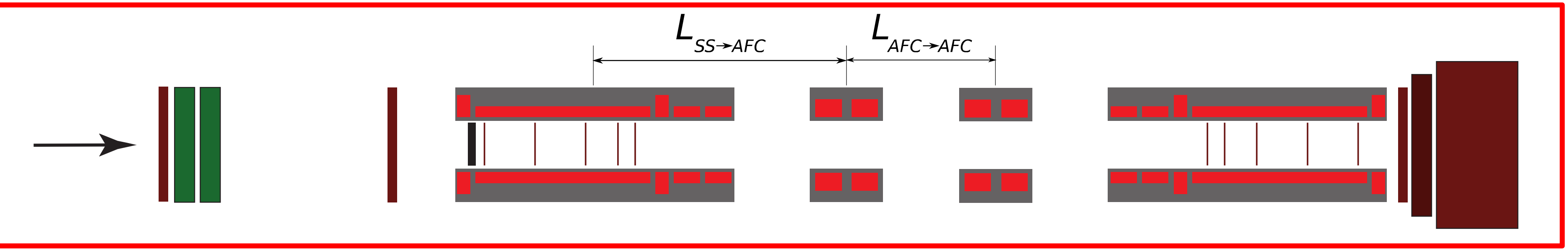
Step IV


SS's and Trackers
Upstream
Kalman Recon
400
350
300
250
200
150
100
50
AFC
TOF/KL
EMR
Racks

MICE Hall

Development of cooling demonstration design:

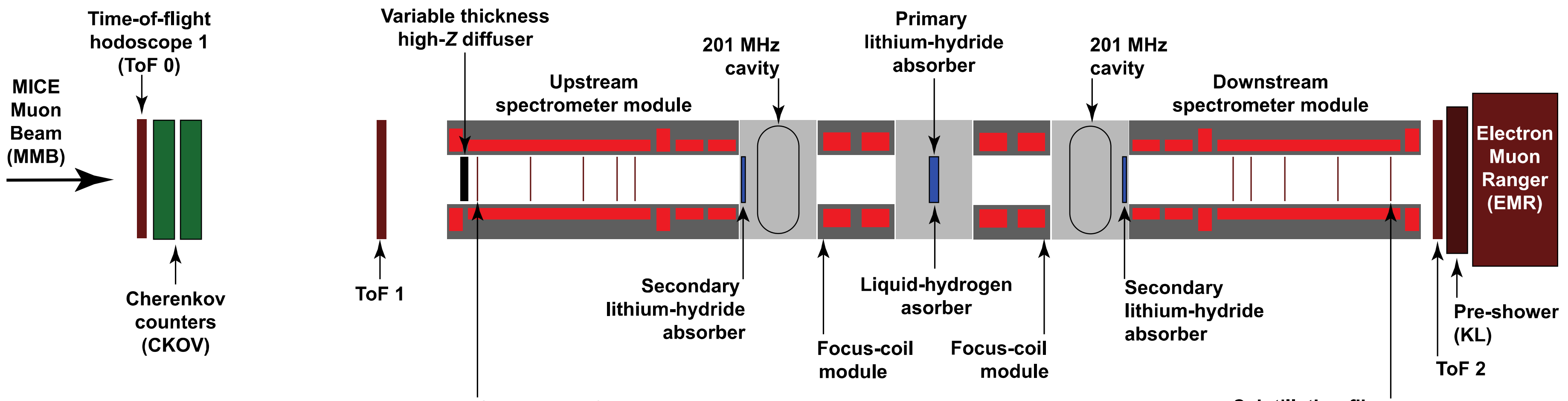
- Initially classified possible lattices using:
  - Two focus coils, note no CC;
  - Two cavities;
  - Single LiH absorber module
- Gaps between solenoids were populated with all logical combinations of cavities and absorbers



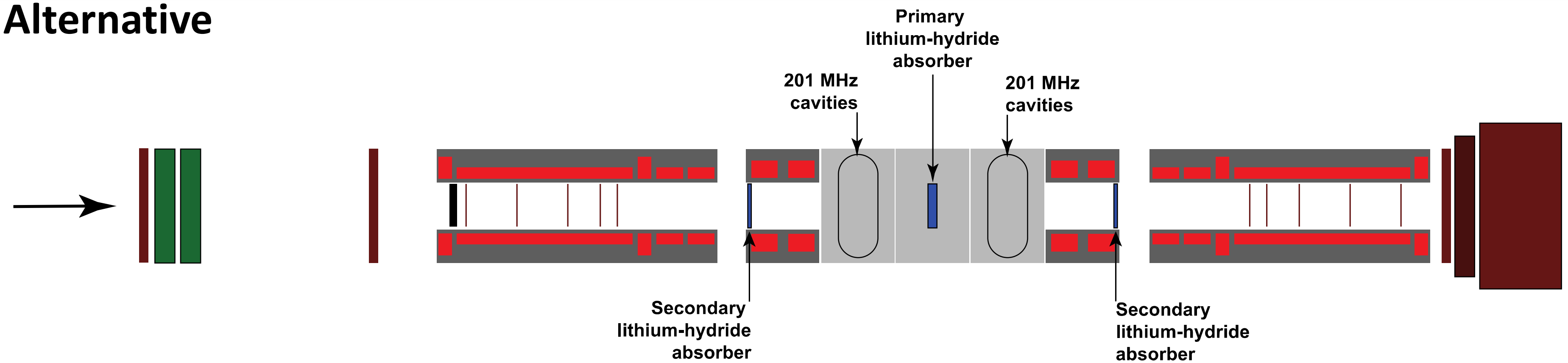
- Linear optics used to study beta-function, energy loss and expected cooling performance
- The two lattices that performed best were identified and selected for further analysis

Reference and alternative:

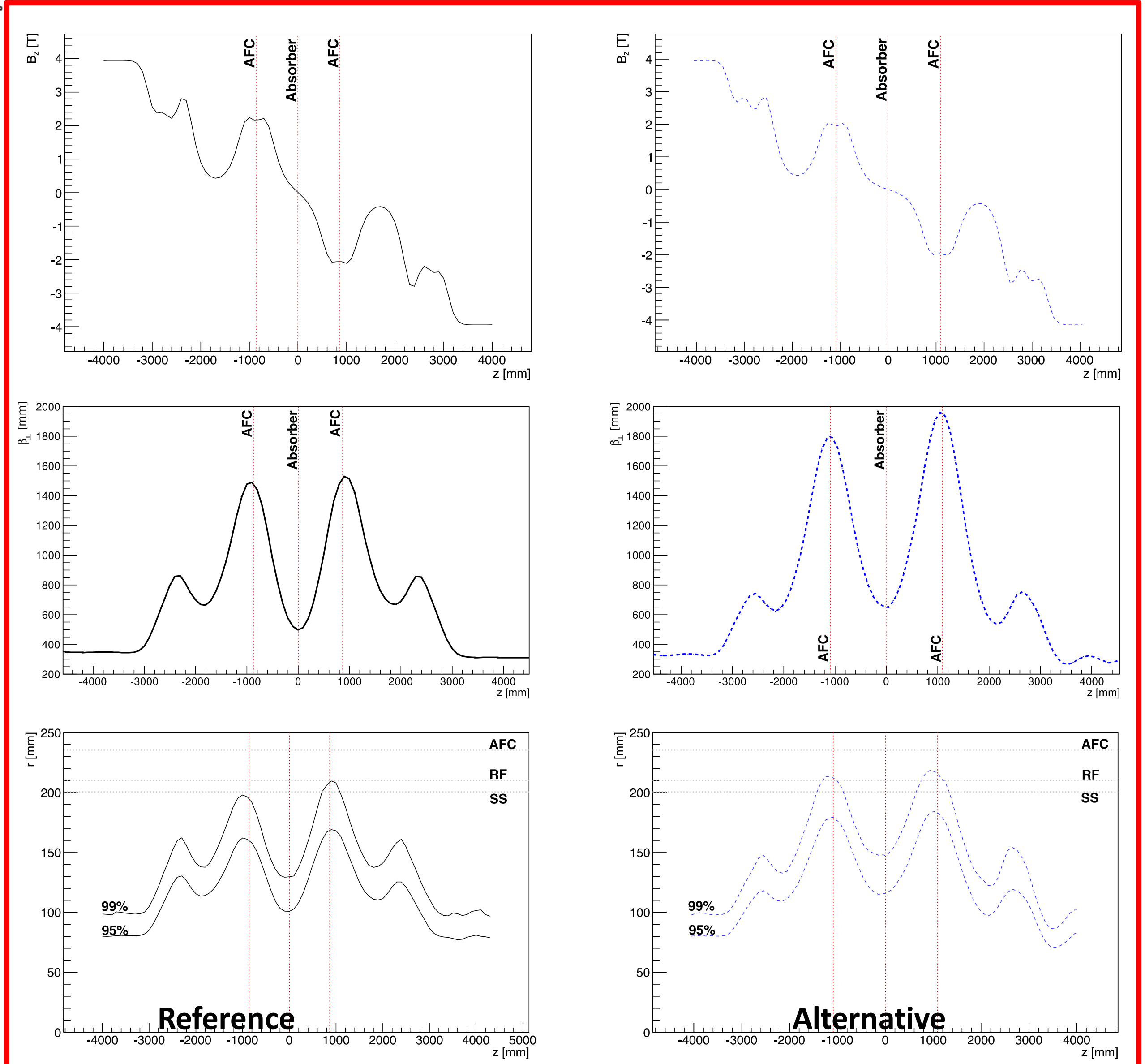
Reference



Alternative



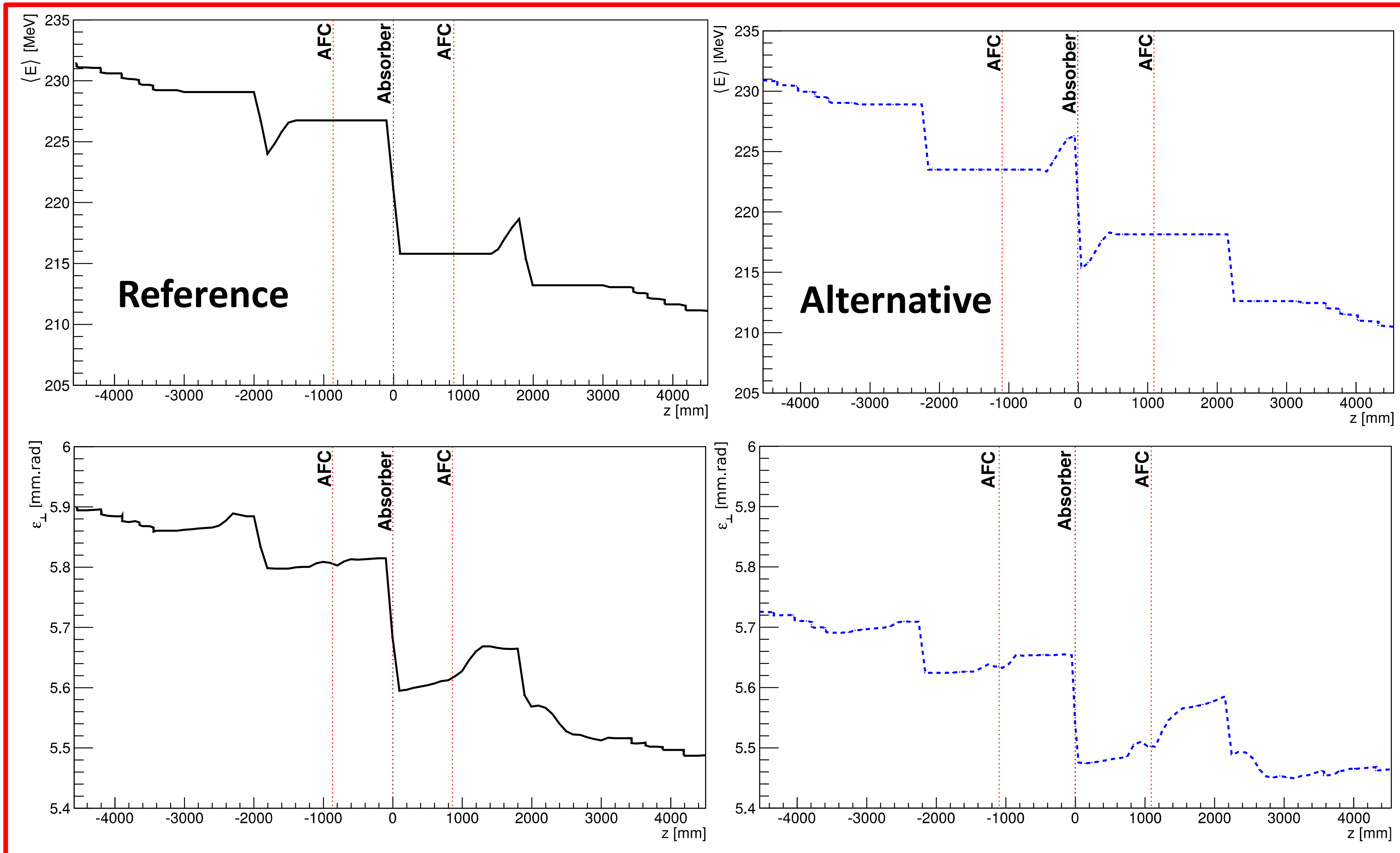
Beam dynamics in both lattices



- ++ -- configuration preferred
  - Field-flip in centre of cell
- Reference yields smaller beta at central absorber and smaller maximum beta
- Reference has smaller excursions in radial direction:
  - Aperture limitations less severe for reference

Beam dynamics in both lattices(2)

Imperial College London



- Cooling effect in reference stronger:
  - Result of more advantageous beta function

Criteria:

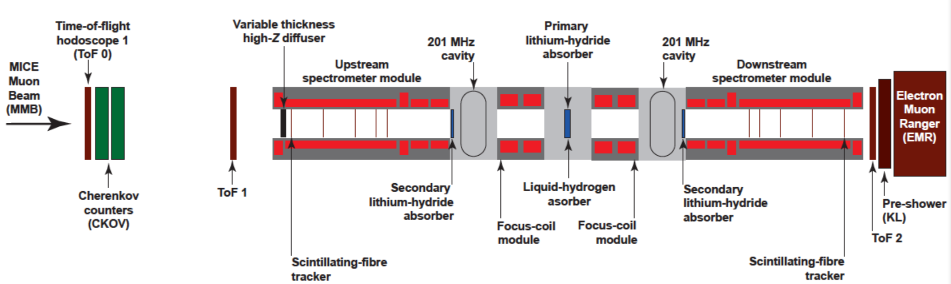
- Priority-ordered criteria agreed at CM40, Rome Oct14:

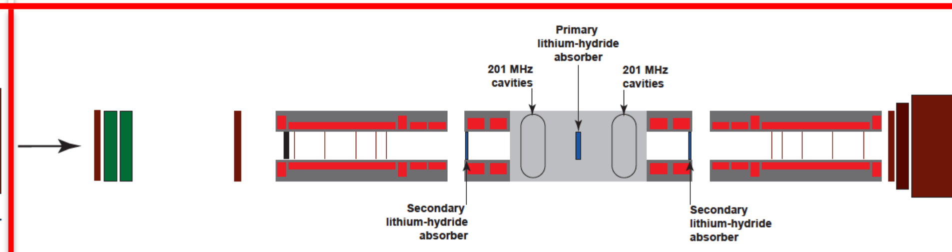
1. 4D emittance reduction; transmission/scraping:
   - Have not (yet) studied full simulation/reconstruction;
   - Therefore essential that configuration adopted produces largest 4D cooling effect;
     - Best chance for systematic study.

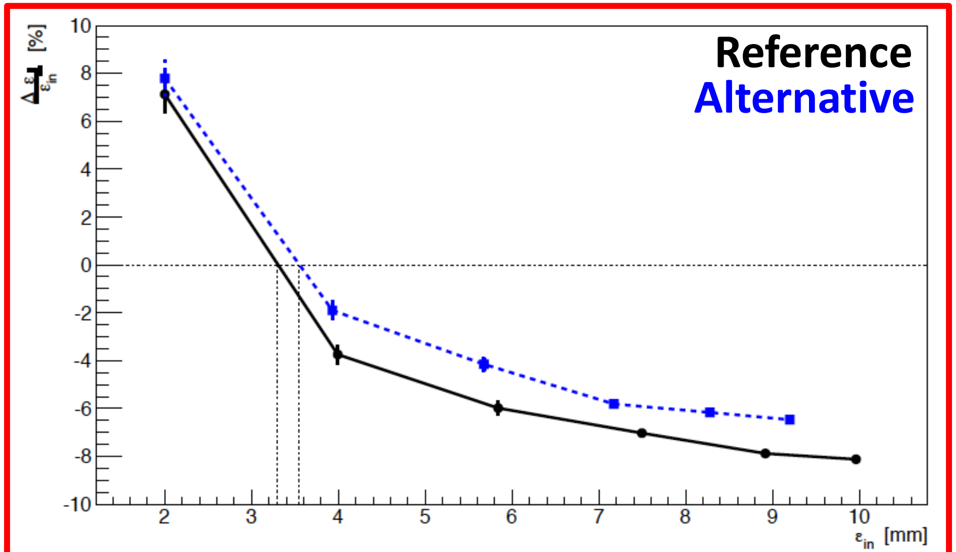
2. 6D emittance reduction:
   - Largest change in 6D emittance presented at recent CM at ~1% level;
     - Confirmed for reference and alternative since; still under study;
     - Very large data sets likely to be needed to measure such a small effect;
     - 6D emittance reduction is a desirable, rather than essential.

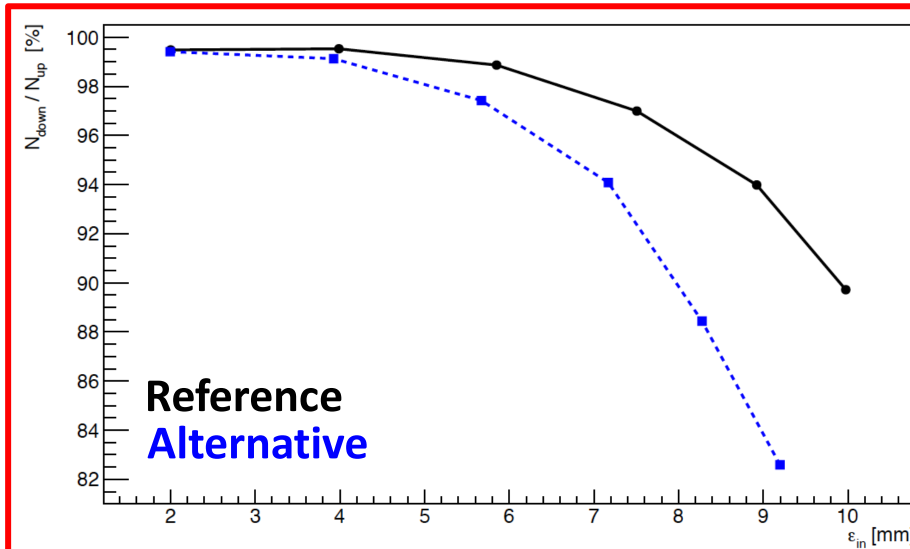
3. Lattice cell:
   - MICE approved to demonstrate "realistic" section of cooling channel;
   - Ideally cell constructed would be part of an extended cooling channel;
   - Implies appropriate matching criteria;
     - Applied in developing reference/alternative;
   - Lattice cell suitable for incorporation extended channel desirable.

Performance Comparison:



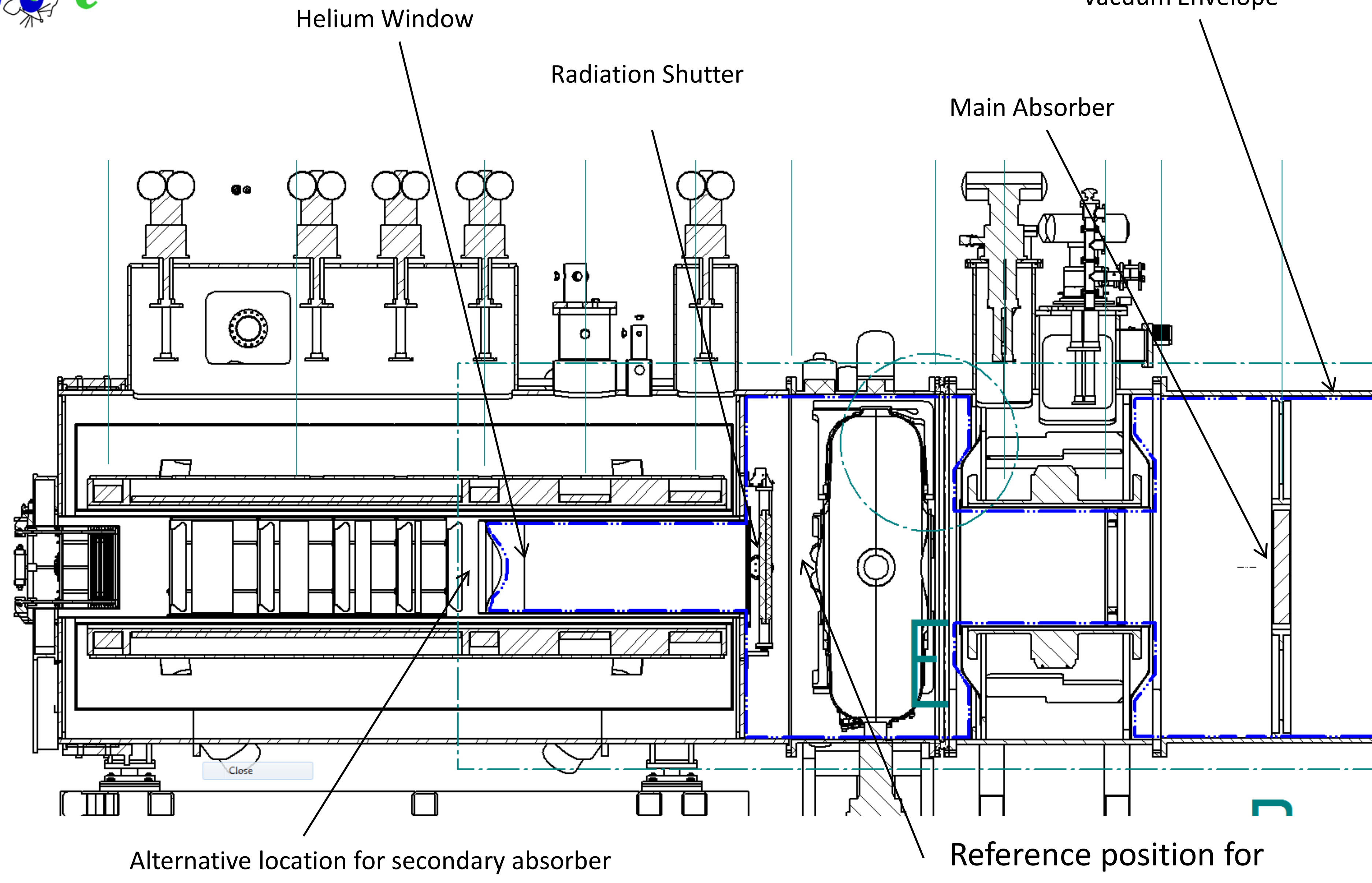






- Reference lattice therefore confirmed:
  - Studies of 6D performance in hand:
    - Indication is that performance of reference and alternative is very similar

Engineering of Mice Demonstration of Ionization Cooling



Question to be addressed

- Do we need to have movable Secondary Absorbers?
  - ❑ If yes, can we use the Shutter mechanism?
    - ❑ If not, we need to design an alternative mechanism.
  - ❑ If not, is it better to put them into the SSs?
- What is the optimum distance between FCs?
- The deadline is 18th December!

Conclusions

- Step IV construction is ongoing with the aim to complete 2nd of June 2015.
  - Critical delivery is PRY
- Preparations on all fronts are progressing well
- Scenarios for MICE Demonstration of Ionization Cooling with RF re-acceleration without RFCC have been successfully created.
  - They substantially reduce the risk of the project
- Reference scenario for MDIC has been identified and the design will be frozen soon (18th of December)
- Very positive feedback was obtained at the last MPB -> we have defended the Project!
- MICE is on a good path toward the essential demonstration of the ionization cooling – an essential tool required for our field!